THE ECOLOGY OF SCHISTOSOMA IN PUERTO RICO*

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THE CURRENT ENVIRONMENT FOR SCHISTOSOMA

SCHISTOSOMIASIS continues to be endemic in the Caribbean island of Puerto Rico. This island measures 100 miles by 35 miles and supports 2.6 million people, a population projected to increase by 50 percent within 30 years. This is the third most densely populated area in the world. The burgeoning economy is changing from agricultural to industrial enterprise. Formerly rural, Puerto Rico is becoming a modern suburbia; thus perspectives on the natural history of schistosoma are in transition. Interagency action in the area of research on control of the trematode is strong.[11]

The local disease is part of a regional Caribbean problem.[36] Schistosomiasis is currently endemic in the Dominican Republic, Puerto Rico, Vieques, Guadaloupe, St. Martin, St. Kitts, St. Lucia, Nevis, Antigua, St. Bartholomew, and Martinique.[7, 10, 18-20, 38, 41, 67, 109] It is absent in Montserrat, which has *Biomphalaria glabrata*, and also in Dominica, which has recently imported *Biomphalaria*. Neither Trinidad nor Jamaica has the snail. Schistosoma has been reported from Panama, Cuba, Aruba, and the U.S. Virgin Isles in transients. There are no reports of the fluke or of the snail from the Bahamas or Haiti. Since *Biomphalaria* must surely be carried about by attachment to the body of birds and bovines, and since *Schistosoma mansoni* is easily transported in modern man with his ever-present urge to travel, control of schistosoma in just one of these islands possesses limited utility over the long range. Obviously, survey of the problem in all affected Caribbean islands, with development of synchronous control projects, would be mutually beneficial to the several governments involved.

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The Trematode, *Schistosoma mansoni*

At the turn of the century it was disclosed by the brilliant work of Dr. Isaac González-Martínez of Mayaguez, Puerto Rico, that some of his patients who had suffered with a debilitating disease had the trematodes in their portal veins at autopsy. Later these trematodes were determined to be a new American form—Manson's blood fluke, *Schistosoma mansoni*.[7, 18, 23, 25-29] *S. mansoni* with its laterally spined egg is still the only human schistosome in the Americas, and there are no closely related forms. *Biomphalaria* is host to several avian flukes in Puerto Rico which do not infect man.[94, 100] Warm-blooded animals do not appear to be host to *Schistosoma* in Puerto Rico. Curious carriage of viable eggs of *S. mansoni* in the intestinal tract exists in the common giant Surinam toad, *Bufo marinus*, because of the coprophagous habits of this animal.[85]

Studies have been made of characteristics of single-sex worm infections; adult male schistosomes undergo apparently normal development while female schistosomes remain small and immature. Bisexual infections in snails probably predominate in endemic foci.[52]

Studies have been made on resistance to infection in animals[87] and there is growing belief in the ability of man to resist the disease partially.

Although there is no recorded indication of change in the host-parasite relation,[53] schistosomiasis in Puerto Rico is now judged to be relatively mild compared to descriptions given about 15 or more years ago.[1, 3, 9, 24, 26, 35, 45-50, 61, 62, 73] The disease does appear to be mild in comparison with its typical expression in Brazil and Africa. In this we are indeed fortunate. The course of Puerto Rican schistosomiasis may be affected beneficially by a high protein diet,[5] and it is to be hoped that current improvement in dietary status is partially responsible for the so-called mildness of infection. Symptoms remain about the same as described at the turn of the century except that acute cases are rare and the percentage of chronic cases exhibiting hepatomegaly and splenomegaly is low. The bulk of infections fall in the intermediate class: some are sporadic gastrointestinal and some are asymptomatic. There is considerable interest in the associated portal hyptertension and sequelae in the chronic case.[22] Surgical intervention is practiced in some cases of esophageal varices. Only incidental attention has been paid to longevity of infection. A few infections may last for decades.[12]

The Puerto Rican strain of *S. mansoni* has been well studied under laboratory conditions.[79, 109] The susceptibility of common experimental animals to infection has been studied; albino mice and Rhesus monkeys are excellent hosts. This is true also for *Cercopithecus sabaeus*, a monkey which was at one time a natural host in St. Kitts, British West Indies.[19] The Puerto Rican hog may be a potential host.[68]

Diagnostic data on schistosomiasis have been summarized as a prelude to a recent island-wide survey of antigen-antibody reaction, carried out by intradermal injection of material derived from adult worms.[10, 13, 18, 35, 37, 39, 40, 42, 47-50, 54-56, 60, 64, 75, 82, 112, 115, 117] Laboratory data and clinical records indicate that the prevalence of schistosomiasis probably has remained in the range of 10 to 20 per cent during most of this century. By comparison of various types of test data, it is concluded that the present prevalence is about 15 per cent. This refers only to evidence of present or past infection and not to degree of disease. The skin-test survey by Kagan *et al.* covered all children in the 5th grade in 390 randomly selected schools from December 1962 to June 1963; 12 per cent of 10,824 children were positive.[44]

Schistosomiasis is distributed in Puerto Rico unevenly. It may be characterized as both a rural and suburban disease, and it is present in both mountain and alluvial plain provinces. Most cases occur east of a line drawn from Arecibo to Ponce; this includes Utuado. West of this line only pockets of infection exist, notably in suburbs in Mayaguez and Añasco.[44] Schistosoma may be detected in adults of the six municipalities of the irrigated Lajas Valley, but there is no present evidence of transmission there. Eastern Puerto Rico has many small pockets of infection and certain valleys are known as classic foci—Barranquitas, Aibonito, Comerío, and Caguas. There are strong foci at Humacao, Ceiba, Fajardo, and Rio Grande. Except for the suburbs of Rio Piedras and Bayamón, the San Juan metropolitan area is free from infection potential. Environmental factors in selected endemic foci have been described.[115, 116]

The biology of the egg stage is incompletely known despite the classic investigations of Faust, Maldonado, and Rowan.[9, 53, 89, 91, 104, 106] Special techniques for the study of eggs obtained from tissues of the human intestine, from sewage, or from fecal samples have been developed.[21, 35, 82, 84, 90, 104, 105-107, 110, 116]

The conditions under which miracidia hatch in the laboratory or

in simulated field conditions have been investigated extensively.[8, 53, 83, 89, 91-93, 104, 106, 108, 112] Miracidia are erratic, penetrating the soft parts of *Biomphalaria* at any point. The tentacles of the snail may become swollen as a result of penetration. If 7 or 8 miracidia are used per snail, 75 to 80 per cent of snails will be infected. If only one miracidium is used per snail, the infection rate drops to 10 to 20 per cent. From 30 to 40 days are needed for maturation and release of cercariae in the laboratory.[34] Theoretically, one miracidium can result in the production of 300 cercariae. Miracidia do not feed; they spend their 8-hour life in aimless swimming, and their contact with snails seem to be accidental.[81] Information on the biology of miracidia is sparse, but much work has been done on details of their anatomy.[95]

Part of the research on the cercariae of *S. mansoni* in Puerto Rico has centered on the conditions for escape from *Biomphalaria* as seen in the laboratory.[8, 40, 65, 83, 88, 98, 102] Larvae emerge under their own power mostly from 9:00 a.m. to 2:00 p.m. The peak of production both in laboratory vessels and in streams occurs approximately at noon. Emergence is greatly decreased when snails are kept in the dark. Unusual temperature manipulations decrease cercarial emergence.

Within certain ranges of water velocity, penetration of mice exposed in streams may be expected to increase.[96, 103] Cercariae have surprising abilities to penetrate materials such as columns of wet sand, concrete pipes, and some but not all types of military clothing, although they may be deterred significantly by certain protective salves from penetrating human skin.[83, 108]

Ingenious devices have been developed for quantitative recovery of cercariae from Puerto Rican bodies of water by Block, Rowan, and Butler,[80, 86, 101] and studies of seasonal population dynamics in streams are in progress. There is presumptive evidence that cercariae may penetrate the buccal mucosa from drinking water. *It is the current consensus in Puerto Rico that most infections occur first as young children play in contaminated water.* Production-line techniques have been developed for massive concentration and lyophilization of *S. mansoni* cercariae for the manufacture of skin test antigens by the U.S. Army, the Laboratory Branch of the National Communicable Disease Center, and the Department of Medical Zoology of the University of Puerto Rico.

There is no schistosomiasis problem in brackish water canals or brackish lagoons. The area of mixing of sea water and endemic stream

water should be avoided, since cercariae can survive long enough there to penetrate the skin.[108]

The Snail Intermediate Host, *Biomphalaria glabrata*

The schistosoma snail has been the subject of much investigation in Puerto Rico and will continue to be so treated. It has been taxonomically defined and placed in the modern systemic scheme[2, 17, 20, 43] and is now known as *Biomphalaria glabrata.* Only *B. glabrata* has been found infected in nature to date; yet several local snails will accept the miracidium under laboratory circumstances (in descending order of frequency of penetration: *B. obstructus, B. glabrata, B. riisei., B. albicans, Aplexa marmorata, Plesiophysa hubendicki, Drepanotrema simmonsi*). However, only *B. riisei, B. albicans,* and *B. glabrata* became infected and shed cercariae.[97, 99] *B. obstructus* appeared in St. Croix in 1966 and has dispersed widely in ponds.

Eggs of *B. glabrata* are deposited in flat masses on a variety of solid objects such as vegetation, rocks, other snails, toads, or other animals. Young adults produce an average of 11 eggs per clutch, older snails an average of 28 eggs per clutch, and from one to two clutches per day. The period of incubation is about eight days. Hatching to egg-laying requires about 21 days.[70] Snails with a diameter as small as 8 mm. and only three weeks old can lay eggs.

Snails attain a diameter of about 18 mm. in one year. It probably requires about two years for them to reach a diameter of 30 mm. The maximum size observed in Puerto Rico is 33 mm; this occurs rarely. *The egg-to-egg cycle requires about one month.*

A great variety of organic materials serves as food for the snails, which apparently prefer decomposed to fresh materials. In the laboratory they thrive on leaf lettuce, dried malanga root, or on modifications of the Standen snail food formula (cereal, powdered milk, alginate, etc.) or on a new diet formulated by Butler.[4] *Biomphalaria* does not demonstrate preference for specific aquatic plants, but malanga is a reasonably good "indicator plant." This *Caladium* is usually found associated with either aquatic or marginal vegetation.

If *Biomphalaria* is wiped out of a habitat by chemical treatment or by stream flooding, and if a few snails are replaced by subsequent flooding or by other unknown means, *repopulation is rapid, and in about three months the colony will have been revitalized.* The finding of only

large snails and few or no egg masses usually indicates the terminal decline of a colony. Remarkably, however, it is rare to find a mixture of small, medium, and large snails in a habitat. Colonies containing only small snails are rare. There appears to be no stabilization in *Biomphalaria* colonization as based on gross observations. In the laboratory it has been shown that crowding seriously affects colonization by lowering the egg-laying capacity. This has not been studied under field conditions.

Biomphalaria is known to be dispersed by flooding in streams, normal flow in irrigation canals, and wave action in impoundments (depending upon prevailing wind directions). Eggs have been seen attached to the skins of toads and to the surface of large water beetles. However, probably the most important factor is attachment of young snails to the legs of birds and the feet of cattle, although there is no proof of this.

Biomphalaria will survive for several weeks if accidentally buried in streamside mud, and laboratory studies showed that it has survived burial under soil and plant debris for four months. Thus a part of a snail colony can probably endure any short-term drought expected in the tropics. *Biomphalaria* can withstand hydraulic pressure found at depths of 50 to 60 feet in the large lakes and it has been carried for about 10 miles in underground tunnels at high velocities.

Biomphalaria may be affected by worm parasites, protozoa, or bacteria. They are commonly eaten by rats, which probably fish them out of shallow water or receding water. They are destroyed by fire ants. In regard to predation by fishes, *Biomphalaria* is readily eaten by *Lepomis microlophus* and *L. auritus*, the shellcracker and the redbreast. Another fish, *Tilapia melanopleura*, also has biocontrol possibilities because of its omniverous nature (specifically, destruction of algal mats).

Biomphalaria commonly occurs in association with a variety of other snails without apparent ill effects. It has been demonstrated, however, that it can very rarely survive in association with *Marisa cornuarietis*, the predator snail, which is used for biological control.[15, 16, 18, 30, 31, 33, 34, 57, 58, 63, 66, 67, 69, 74, 76, 111-114] Also, there is gross evidence that *Tarebia granifera mauiensis* interferes with *Biomphalaria*, but the method is unknown.

Location, number, size, and type of bodies of water determine the presence and population intensity of *Biomphalaria* in Puerto Rico. In general there are fewer snails to be found south of the central escarp-

ment, and a gradual decline in numbers is observed as one goes westward from Bayamón on the north coast. This decline is also noticeable on the southern alluvial plain. The distribution of *Biomphalaria* is affected by the pattern of rainfall that provides aquatic habitats, since the northeast prevailing winds release most of the moisture in a general northeast-southwest gradient as well as an east-west gradient in coastal areas. Building of artificial lakes (of which there are 25 named units) has not had a great effect on distribution except in isolated instances. Because of the dynamic nature of these impoundments on an annual basis, they are usually inhospitable to *Biomphalaria.* Some few have developed sizeable colonies of *Biomphalaria* in the past decade (Lago Carite, Lago Patillas, Lago Cidra, Lago Guajataca). Man-made irrigation channels at times may become ideal habitats depending upon stability of flows and amounts of submersed aquatic vegetation serving as snail food, protection, and egg-laying surfaces. Stream gradients above about 2 per cent are harmful during wetter seasons.[31, 57] Some types of swamps and swampy terrain afford ideal breeding sites. Most ponds, whether of the stable USDA type or of the unstable represa type associated with irrigation farming, will support the vector snail. Drying and cleaning of the latter units is unfavorable to *Biomphalaria.* Soil type does not appear to be influential in aiding or deterring this snail except that there is a great paucity in streams of the limestone area extending west of the San Juan-Bayamón area in northern Puerto Rico; yet ample samples may be taken from limestone sink ponds. Instability characterizes *Biomphalaria* populations when viewed over several seasons,[69] and this points up the remarkable persistence of the parasitosis despite the many difficulties that it encounters. A great variety of useful research has been performed in detailed fashion on the ecology of the vector snail.[2, 6, 8, 15, 17, 19, 30-34, 43, 57-59, 63, 65-67, 69, 71, 72, 74, 76, 83, 97-99, 111, 113-115]

B. glabrata is a formidable foe because: 1) usually only a low percentage of infected snails in a colony associated with human habitation will maintain the disease; 2) snails of both small diameter (2 to 3 mm.) and of larger size can become infected; 3) snail infections possibly mature within 30 days in the field; 4) resistance to desiccation is marked, allowing survival for many weeks in moist conditions of terrain; 5) time required for reinfestation of a habitat is short, probably about one month; 6) self-fertilization is a strong factor in perpetuation of the species; 7) it is adapted to a great variety of freshwater environ-

ments; and 8) it may be transported to new sites of action by currents of streams, or by attachment to objects or animals, and active vagility (walking motions).

Discussion

The broad view of Puerto Rican schistosomiasis may be enhanced by consideration of the following factors: 1) it is insidious and exhibits slow attrition; 2) ignorance is widespread about preventive measures; 3) there is carelessness in the sanitary disposal of human wastes, exclusive of the utilization of common modern facilities for the treatment of sewage; 4) practices of contacting water in a tropical climate are crucial and determinative; and 5) the mechanism for maintenance of the disease above threshold is unknown.[51] The vector snail is highly adaptive to changing environments.

Since the ecological basis of the control of schistosomiasis is still experimental, some ideas on future research may be submitted for consideration: 1) the longevity of adult *S. mansoni* in the absence of any possibility of reinfection; 2) localization of remaining foci of infection in demonstration control project areas; 3) factors in the field biology of miracidia and cercariae significant in programs of control; 4) the definitive study of actual or potential carriage of *S. mansoni* in warm-blooded animals stimulated by recent findings in rodents and cattle in Brazil; and[77, 78] 5) prevention of the infestation of new irrigation systems by schistosoma.

Summary

Historical review is made of information on various factors contributing to the ecology of schistosomiasis mansoni in Puerto Rico. The currently mild clinical expressions are compared to those observed in the recent past. Intra- and extramolluscan phases of the parasitic cycle of *Schistosoma mansoni* are discussed. Diagnostic data are summarized, including surveys for presence of the blood fluke ova and intradermal and serologic testing. Rough estimates based upon fecal sampling placed the over-all insular prevalence at about 15 per cent in the past, while a massive synoptic intradermal test program in 1963 yielded a rate of about 12 per cent in older school children. Biological data on the egg, miracidium, and cercaria of *S. mansoni* are reviewed. Factors in the epidemiology are presented in light of the changing socioeconomic scene in Puerto Rico.

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